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A PRELIMINARY ANALYSIS OF TWO SOUND RANGING ALGORITHMS.(U)

JUL 77 W MILLER, B ENGEBOS

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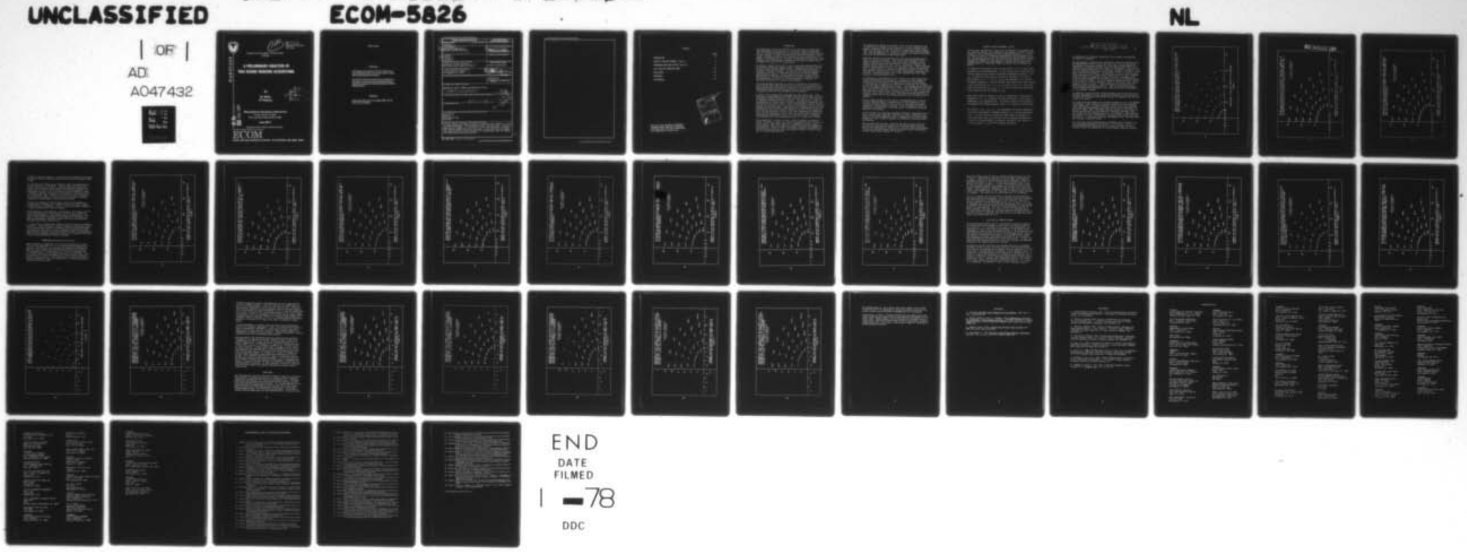

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A PRELIMINARY ANALYSIS OF TWO SOUND RANGING ALGORITHMS

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By

W. Miller
B. Engebos

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Atmospheric Sciences Laboratory
US Army Electronics Command
White Sands Missile Range, New Mexico 88002

July 1977

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Two sound ranging algorithms are examined by observing their behavior in a basic controlled environment. The consistency of both is verified under a variety of meteorological regimes and a selection of arrival time accuracies. The advantages and shortcomings of each are discussed. In particular, possible compromise between timing accuracy and integrity of meteorological data is evidenced. Field applicability may prove feasible.

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CONTENTS

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INTRODUCTION

The traditional use by army artillery of a linear array of sound detection microphones in the solution of a variety of "sound ranging" problems [1] has focused attention on the predictable behavior characteristics of such a system. Of equal interest are the nature and extent of meteorological information necessary for solutions of a given reliability. A number of techniques exist or are under consideration which deal with these problems, and a bibliography of pertinent established or ongoing work is included at the close of this presentation.

At present, interest will be with a set of algorithms developed from [2]. In this work, Miller and Engebos present a mathematical structure within which the sound ranging problem is given a rigorous definition, and a solution is offered in context. The state of the propagating medium is reflected in the form of a quadrivariate function called an extended wave generating function. For the purposes at hand, a simple but revealing form is utilized [3] describing a circular or spherical sound wave propagating in a region of uniform temperature and subject to horizontal translation by a wind of fixed velocity.

The above-mentioned algorithms are simple in form and are structured in such a manner that system failure due to reliability or vulnerability may easily be addressed. No barrier is present to the consideration of more comprehensive wave generating functions; hence, more involved and realistic physical states for the atmosphere can be considered.

A series of three specialized algorithms have been constructed. These algorithms are programmed on the HP9830A computer and have been designated as Acoustic Location Programs one, two, and three (ALP-1, ALP-2, ALP-3). Of interest at present are ALP-1 and ALP-2. The program ALP-1 allows the consideration of a linear array of three or more acoustic microphones and requires the following as input: wind and temperature estimates, a family of wave front arrival times at the respective microphones, and a preliminary estimate of source location. Note that errors in temperature and wind and discrepancies in arrival times will appear as errors in source determination. On the other hand, if ALP-2 is utilized, experience has shown that for sufficient accuracy of arrival times, the initial source location estimate may be considerably in error, yet the true source is reproduced. This phenomenon will be discussed more explicitly in the text to follow.

The program ALP-2 is similar to ALP-1 in that it requires an identical input. It differs in that it is capable of operating in one of three correction modes. These three modes are a temperature correction mode, a wind correction mode, and a mode for correcting both wind and temperature simultaneously. As will be seen, these modes can permit considerable reduction in source location error, but generally require a level of accuracy in timing higher than ALP-1.

The program ALP-3 extends all previous results to three dimensions, and in some cases can produce drastic reductions in source location errors. However, a number of special considerations surface which require attention, and this aspect is felt to warrant a separate descriptive documentation. This documentation is currently in progress and should be available soon after the publication of the present work.

Numerical results are now available from more than two thousand exploratory runs of ALP-1 and ALP-2. These results have brought to light a number of properties of linear arrays which tend to validate the conjectures made by Lee [4] and have caused a considerable change in the authors' outlook toward the utility of the linear array. Current thinking based on latest numerical results plus additional analysis has indicated that a linear array of six acoustic microphones may possess certain favorable behavior characteristics if the proper computational algorithms are utilized. The greatest danger lies in the susceptibility of all methodology to timing estimation errors.

An examination of the behavior of ALP-1 and ALP-2 as sound ranging algorithms necessitated the development of a program which could supply a suitably precise data base for an exhaustive check on the consistency of the algorithms in question and under several conditions for accuracy of arrival times and meteorological states. This program was so constructed that if microphone locations and the state of wind and temperature are known, each source point chosen gives rise to a set of arrival times. This first model does not consider terrain influence, position, or time varying meteorological states, but for the special conditions mentioned previously, it produces arrival times of near nanosecond accuracy to a distance of 30 kilometers.

Since a primary purpose of this report is the documentation of some of the more important behavior characteristics of ALP-1 and ALP-2, a sufficiently inclusive number of sound sources is considered to indicate response to differing source locations. Since microphone positions are symmetrical, consideration of 30 sound sources is equivalent to the observation of 60 sources.

As will be seen, all algorithms considered exhibited a negligible error in source location under idealized conditions; for ALP-2, negligible error occurred also with considerable errors in temperature and wind estimates. However, all were in general degraded in performance as timing accuracy was degraded.

Without theoretical barriers, algorithms may now be constructed which can utilize a more thorough knowledge of the meteorological state and hence be more completely in rapport with a realistic physical environment. In this way, work may progress toward the eventual goal of developing a flexible sound ranging package for the Army.

ACOUSTIC LOCATION PROGRAM 1 (ALP-1)

At this point, the behavior of ALP-1 will be observed in an uncomplicated but revealing setting. This algorithm is the simplest of those to be considered. A local rectangular Cartesian coordinate system (X, Y, Z) will be assumed to supply all underlying coordinates in the situations to follow. The present analysis will be expository and directed toward identifying important features of the linear array without obscuration by an overabundance of mathematical embellishment. Results will be taken as the primary objective. Interested readers may consult [2] for mathematical details.

All events will be assumed to occur on the plane $Z = 0$; or in other words, the model will be two-dimensional. As will be seen, this closely parallels existing techniques and permits considerable interpretive analysis. Let (x_0, y_0) denote a source point of interest on the plane $Z = 0$, and for each j among 1, 2, ... 6, let (x_j, y_j) be the coordinates of an acoustic microphone indexed by j. Assume, moreover, that there exists real constants a and b such that for all j, $y_j = ax_j + b$ with $y_0 \neq ax_0 + b$. This stipulates that the family $\{(x_j, y_j)\ j = 1, 6\}$ form a linear array whose extension of baseline does not include (x_0, y_0).

Within some region of interest, it will be assumed that a steady wind of components $(u, v) = \vec{u}$ is blowing, and that this region is of a constant temperature, say k degrees Kelvin. The speed of sound in this region will be assumed to be $c\sqrt{k}$ meters/second, where c is a constant of value 20.06.

The vector $\vec{x} = [(x_j - x_0), (y_j - y_0)]$ represents the distance between the sound source and acoustic microphone indexed by j in the above-mentioned array. It is not difficult to show that under these circumstances, a blast occurring at time t_0 and giving rise to a waveform propagating at a speed of $c\sqrt{k}$ meters/second, if subject to the wind $\vec{u}$, will result in a clean time break, t_j, at the j^{th} microphone defined by

$$t_j = t_o + \frac{\sqrt{(\vec{u} \cdot \vec{x})^2 + (c^2k - |\vec{u}|^2)|\vec{x}_j|^2} - (\vec{u} \cdot \vec{x}_j)}{(c^2k - |\vec{u}|^2)} . \qquad (1)$$

In expression (1), the usual conventions for dot product and magnitude of vectors are employed.

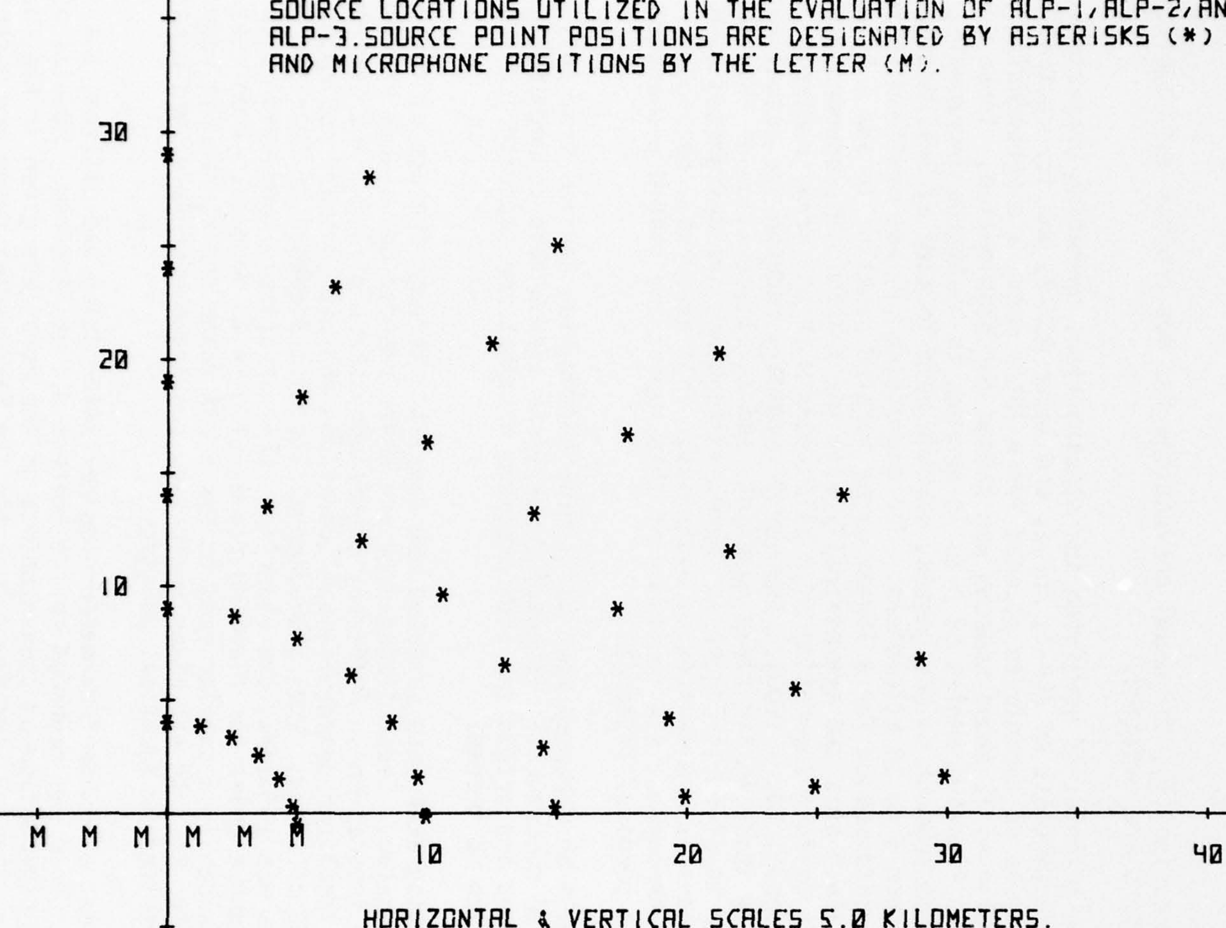
For the purposes of verifying the construction, operating characteristics, and effectiveness of ALP-1, ALP-2, and later ALP-3, and for controlled comparisons of techniques planned for a later date, a comprehensive configuration of 72 sound sources was chosen for examination. These were located at flanking angles of 0 to 75 degrees in 15-degree increments. Along each line segment so designated, sources were located at 5-kilometer increments from 5 to 30 kilometers. The expression (1) was utilized to supply timing information for a linear array located parallel to and 1 kilometer below the X-axis and symmetrically with the Y-axis. Microphones were given a uniform separation of 2 kilometers with the array centroid located at the point (0, - 1000). The use of symmetry reduced the actual calculations to those in the first quadrant, and an illustration of this configuration is given in Figure 1. Here, microphones are designated by M. Sound sources are denoted by asterisks. This array will be used exclusively throughout the remainder of this report and should prove adequate for the purposes intended.

It should be stressed that the timing information derived from this array and used subsequently is based on physical assumptions concerning the environment and originates from programs distinct and separate from the algorithms to be tested.

The timing data were produced and tabulated through the use of the HP9830A minicomputer. These timing data are never rounded but always represent direct truncations. A primary consistency check of ALP-1 was performed under idealized meteorological conditions and with primary estimates 10% and 20% of range. When a 90-degree clockwise sequence of four source locations was utilized, the algorithm ALP-1 invariably converged to the true source point for flanking angles of 0 to 75 degrees. When estimates were chosen in a similar fashion for a 20% range error, results were similar (Fig. 2). In all cases indicated, convergence of ALP-1 was consistent and resulted in identical points.

As a next step, perfect meteorological information was utilized but timing accuracy was degraded to the nearest 0.1 millisecond. Results of such a degradation on chosen points of the array are given in Fig. 3. In Figs. 2 and 3, the deviations for the 5-kilometer range are purposely

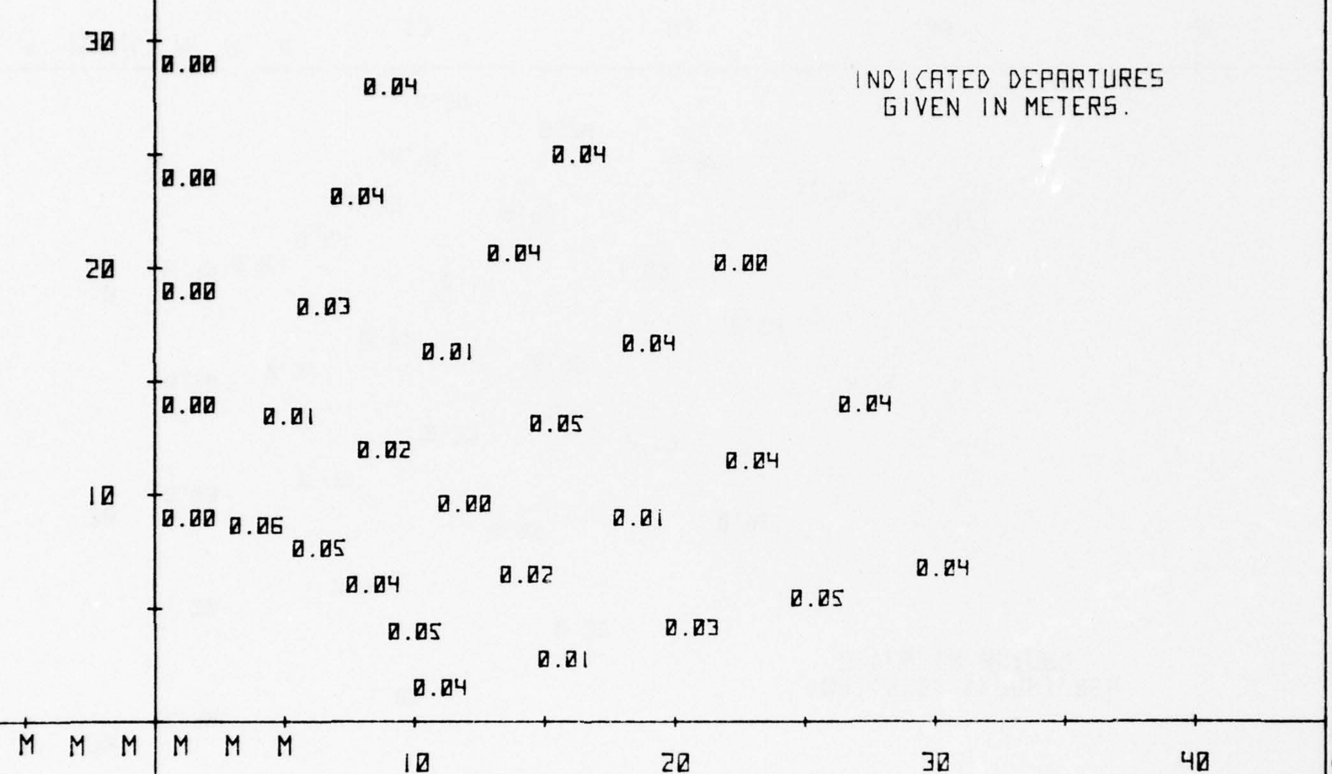
SOURCE LOCATIONS UTILIZED IN THE EVALUATION OF ALP-1, ALP-2, AND ALP-3. SOURCE POINT POSITIONS ARE DESIGNATED BY ASTERISKS (*) AND MICROPHONE POSITIONS BY THE LETTER (M).



HORIZONTAL & VERTICAL SCALES 5.0 KILOMETERS.

FIGURE 1

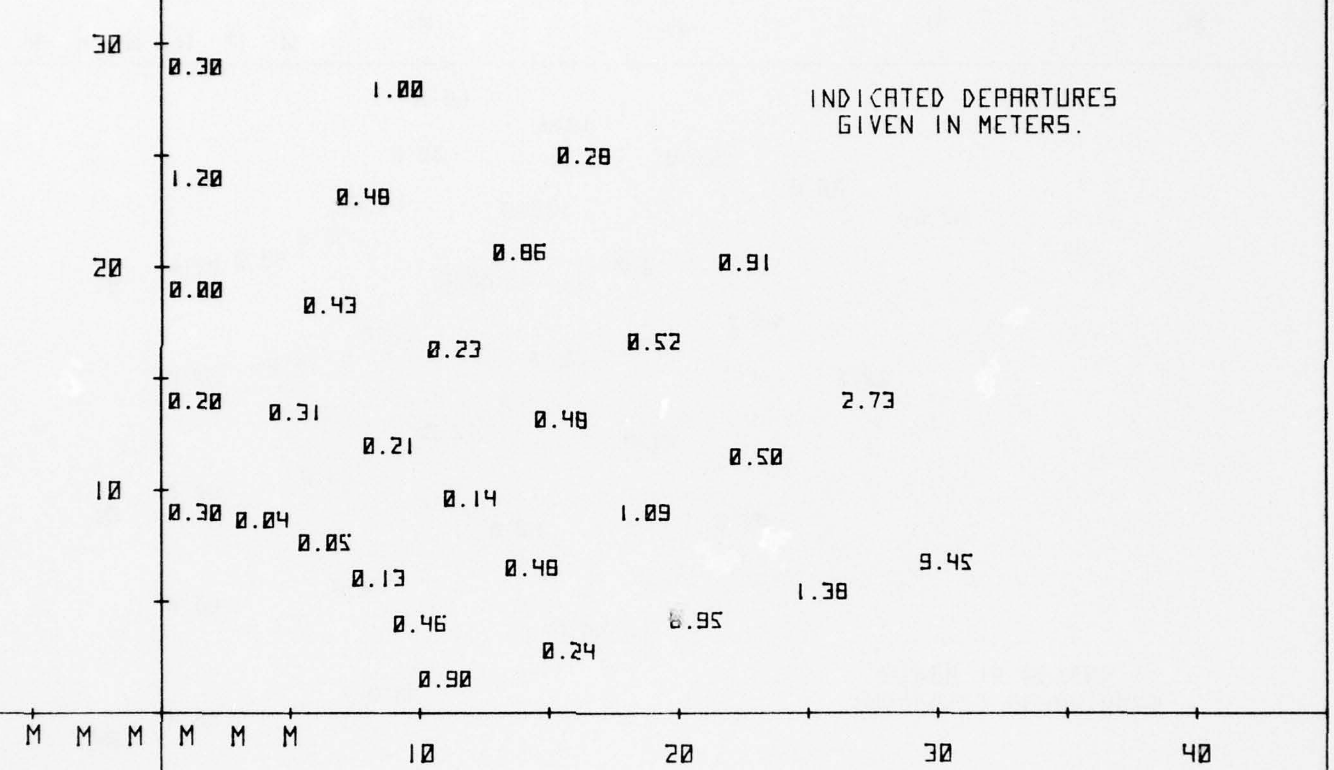
DEPARTURES OF SOURCE LOCATION ESTIMATES FROM ALP-1 PRODUCED BY A 1.0 NANOSECOND TRUNCATION OF ARRIVAL TIMES. HORIZONTAL AND VERTICAL SCALES ARE 5.0 KILOMETERS. (CONSISTENCY CHECK OF ALP-1)



NUMBERS INDICATE DEPARTURES OF SOURCE LOCATION ESTIMATES AT RESPECTIVE POSITIONS AS INDICATED IN FIGURE 1.

FIGURE 2

DEPARTURES OF SOURCE LOCATION ESTIMATES FROM ALP-1 PRODUCED BY A 0.1 MILLISECOND TRUNCATION OF ARRIVAL TIMES. HORIZONTAL AND VERTICAL SCALES 5.0 KILOMETERS.



NUMBERS INDICATE DEPARTURES OF SOURCE LOCATION ESTIMATES AT RESPECTIVE POSITIONS AS INDICATED IN FIGURE 1.

FIGURE 3

omitted for editorial reasons. In addition, these numbers are consistent in behavior with the remaining values and offer little additional information.

The timing accuracy which may be related to ideal field conditions is in the vicinity of 1 millisecond. Figure 4 gives the results of the location algorithm ALP-1 under the previously mentioned conditions, except that a truncation at the nearest millisecond is employed. The degradation from Figs. 2 and 3 is obvious but not unbearable. Figure 5 represents identical information, but expressed in the familiar format of percent of range. Effects of truncation error as a function of range and flanking angle are discernible, but individual truncation characteristics often tend to obscure these relations.

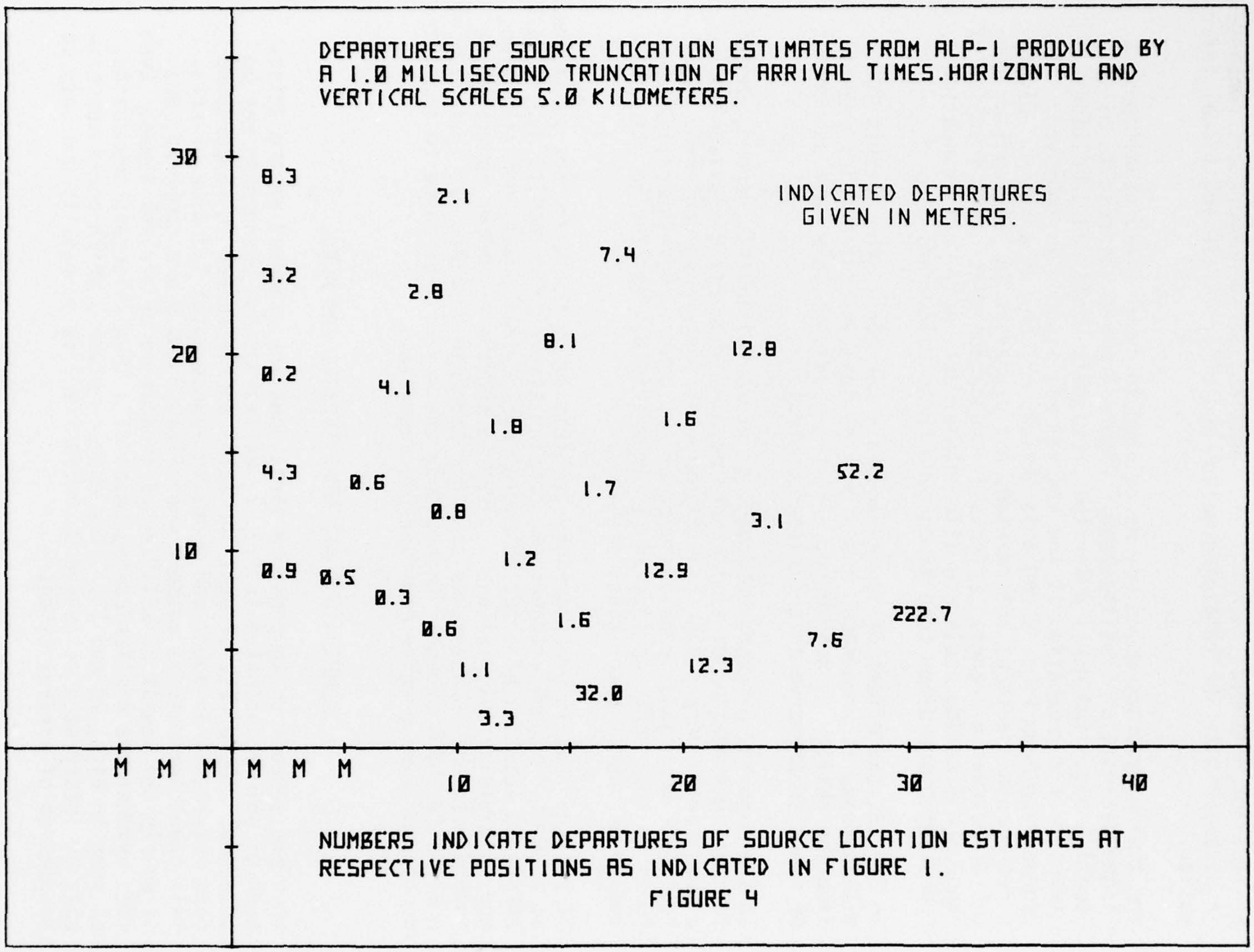
In Fig. 6, the effect of timing accuracy correct to the nearest 10 milliseconds is presented, and a greater loss in source point identification ability is evidenced. Figure 7 presents this data as percent of range to preserve this familiar context.

In the majority of cases observed, or presented in this report, the effects of degradation of timing accuracy are increasingly evident as either range increases or high flanking angles are encountered. This fact will occasionally be obscured by the behavior of truncation effects as they apply to individual times arising from the location of the sound source under consideration.

It is true that in practice many problems arise which are not considered at present. Signal attenuation, complex atmospheric conditions, terrain, errors in location of acoustic microphones, break point identification, and multiple arrival times all serve to degrade or hamper source point identification. However, as the more amenable problems are systematically dealt with and thoroughly understood, the way will be paved to the introduction of more precise and flexible algorithms.

TEMPERATURE AND WIND EFFECTS FOR ALP-1

When the effects of temperature variations are examined at the selection of points indicated in Fig. 1, an interesting phenomenon may be observed. The effect of unit increases and decreases in temperature does not result in equal and opposite source point location effects. This characteristic is evident when Figs. 8 and 9 are compared, and is solely the result of millisecond truncation of arrival times. Even more evident are similar consequences of a 10-millisecond truncation, as seen in Figs. 10 and 11. This characteristic, which could conceivably be interpreted as caused by refraction, is in reality due only to truncation of arrival times.

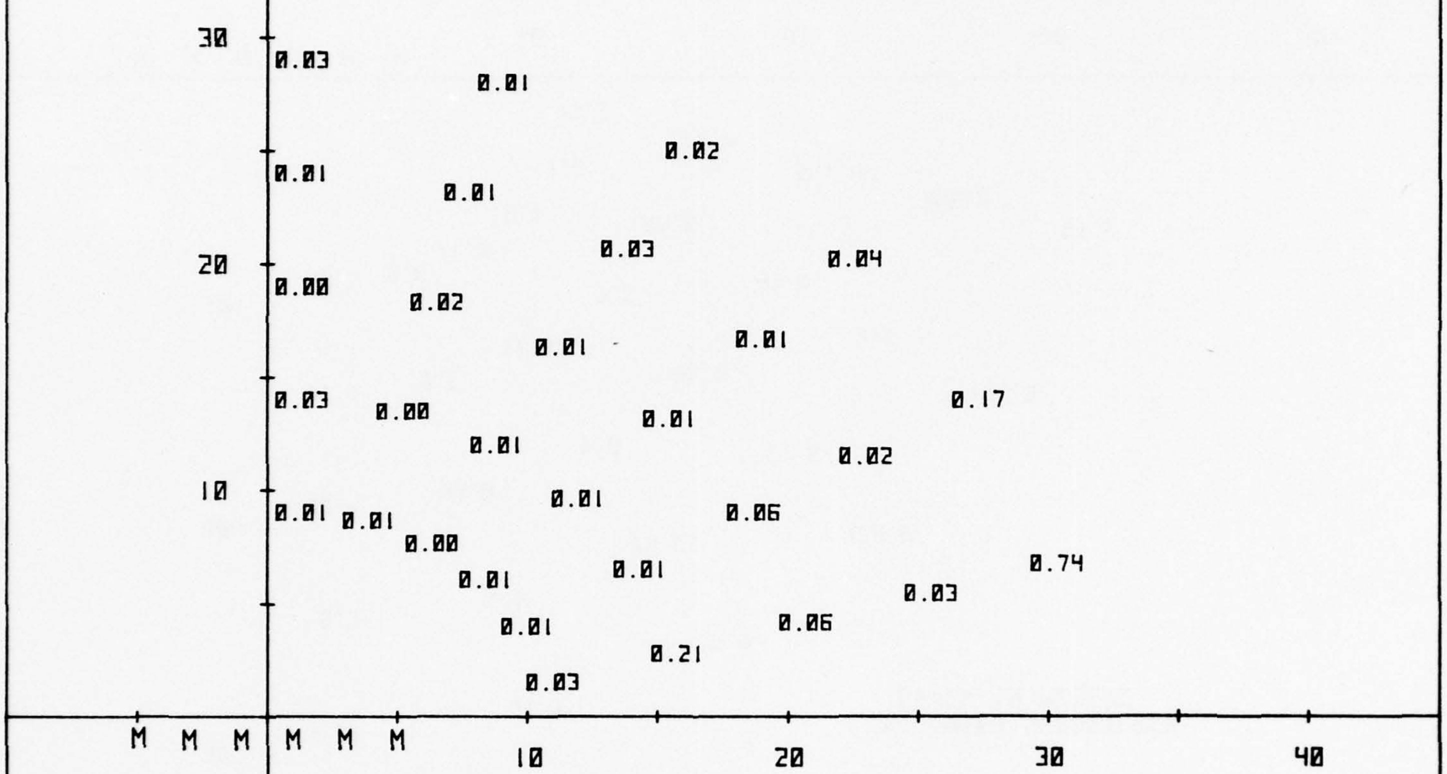


DEPARTURES OF SOURCE LOCATION ESTIMATES FROM ALP-1 PRODUCED BY A 1.0 MILLISECOND TRUNCATION OF ARRIVAL TIMES. HORIZONTAL AND VERTICAL SCALES 5.0 KILOMETERS.

NUMBERS INDICATE DEPARTURES OF SOURCE LOCATION ESTIMATES AT RESPECTIVE POSITIONS AS INDICATED IN FIGURE 1.

FIGURE 4

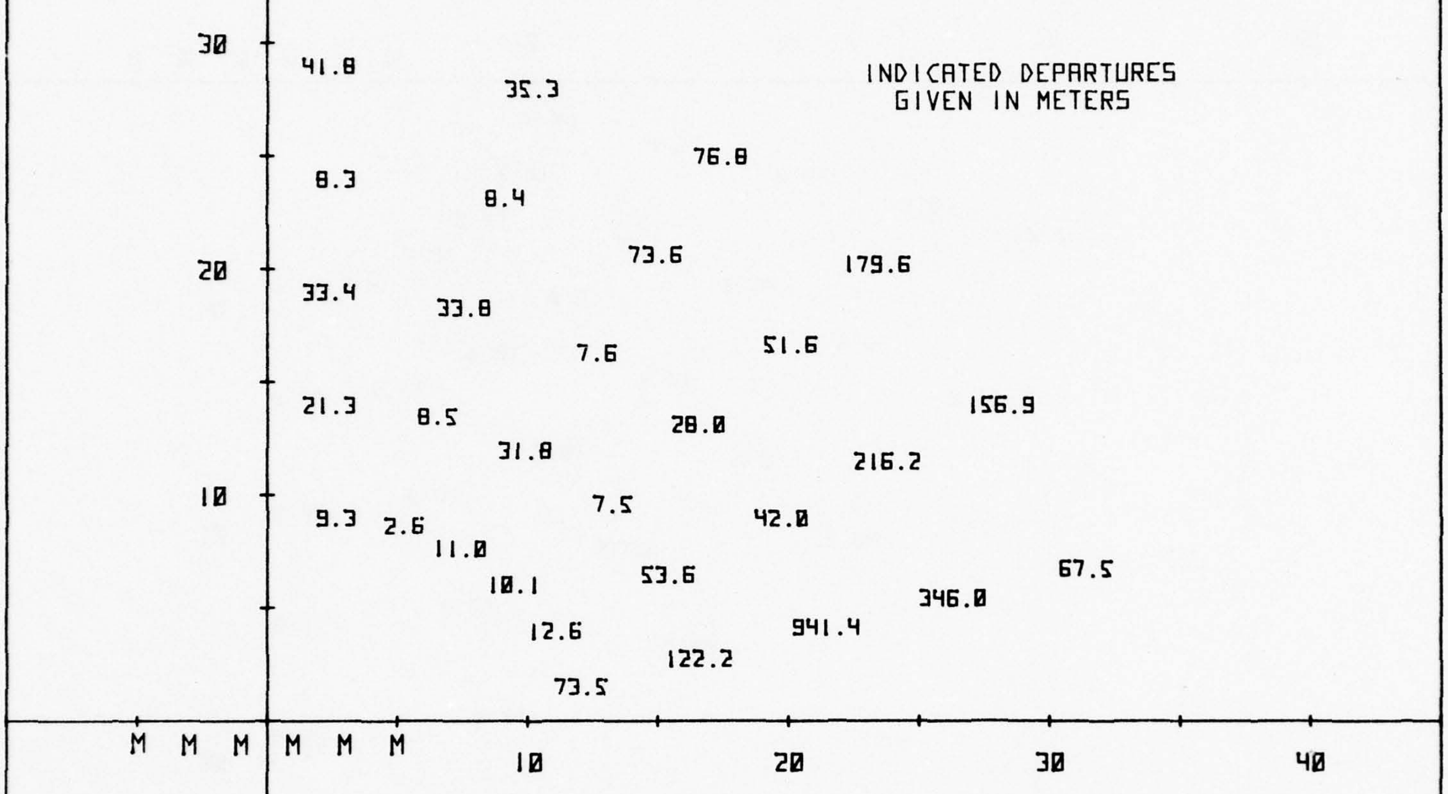
DEPARTURES OF SOURCE LOCATION ESTIMATES FROM ALP-1 EXPRESSED AS PERCENT OF RANGE. ARRIVAL TIMES ARE TRUNCATED AT THE NEAREST MILLISECOND. UNIFORM SCALE REPRESENTS 5.0 KILOMETERS.



NUMBERS INDICATE DEPARTURES OF SOURCE LOCATION ESTIMATES AT RESPECTIVE POSITIONS AS INDICATED IN FIGURE 1.

FIGURE 5

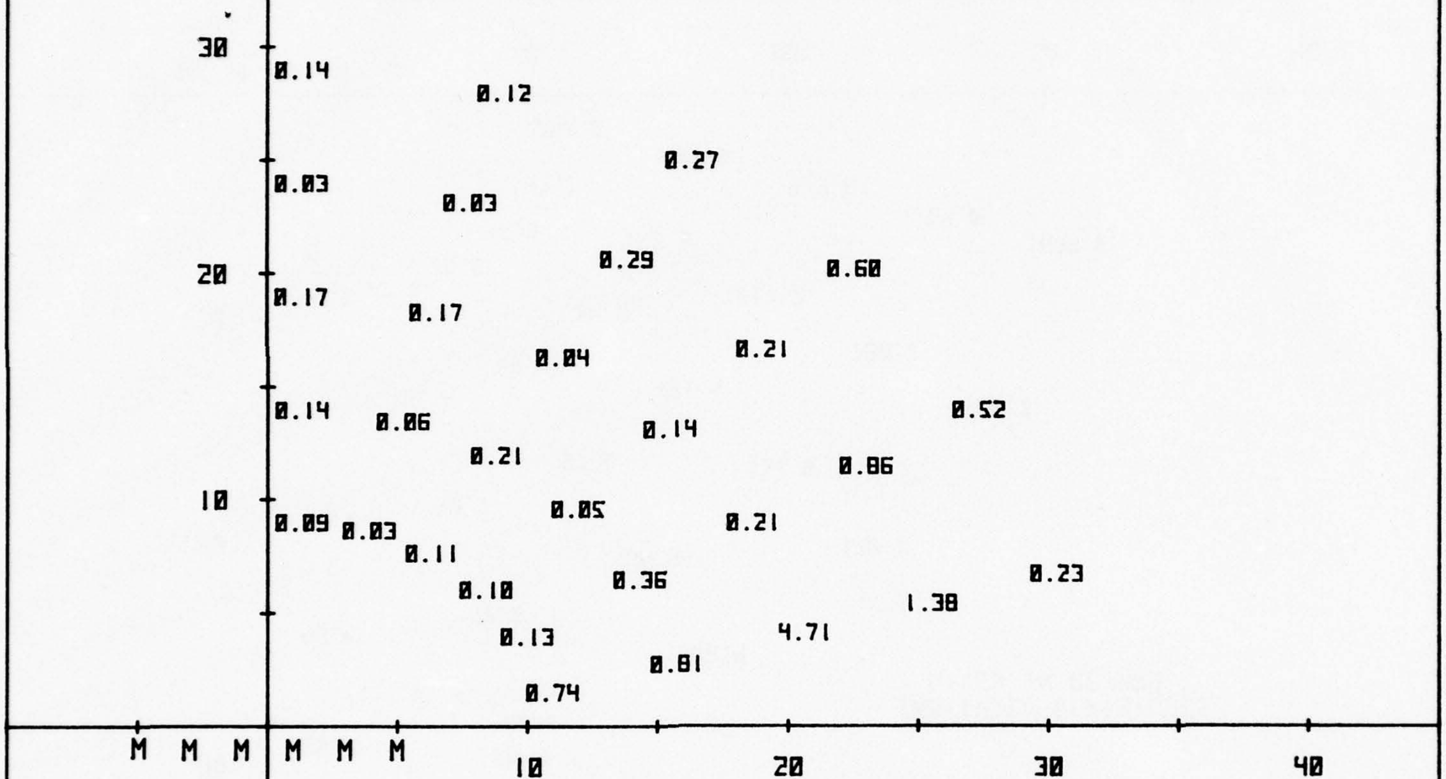
DEPARTURES OF SOURCE LOCATION ESTIMATES FROM ALP-1 PRODUCED BY A 10 MILLISECOND TRUNCATION OF ARRIVAL TIMES. HORIZONTAL AND VERTICAL SCALES 5.0 KILOMETERS.



NUMBERS INDICATE DEPARTURES OF SOURCE LOCATION ESTIMATES AT RESPECTIVE POSITIONS AS INDICATED IN FIGURE 1.

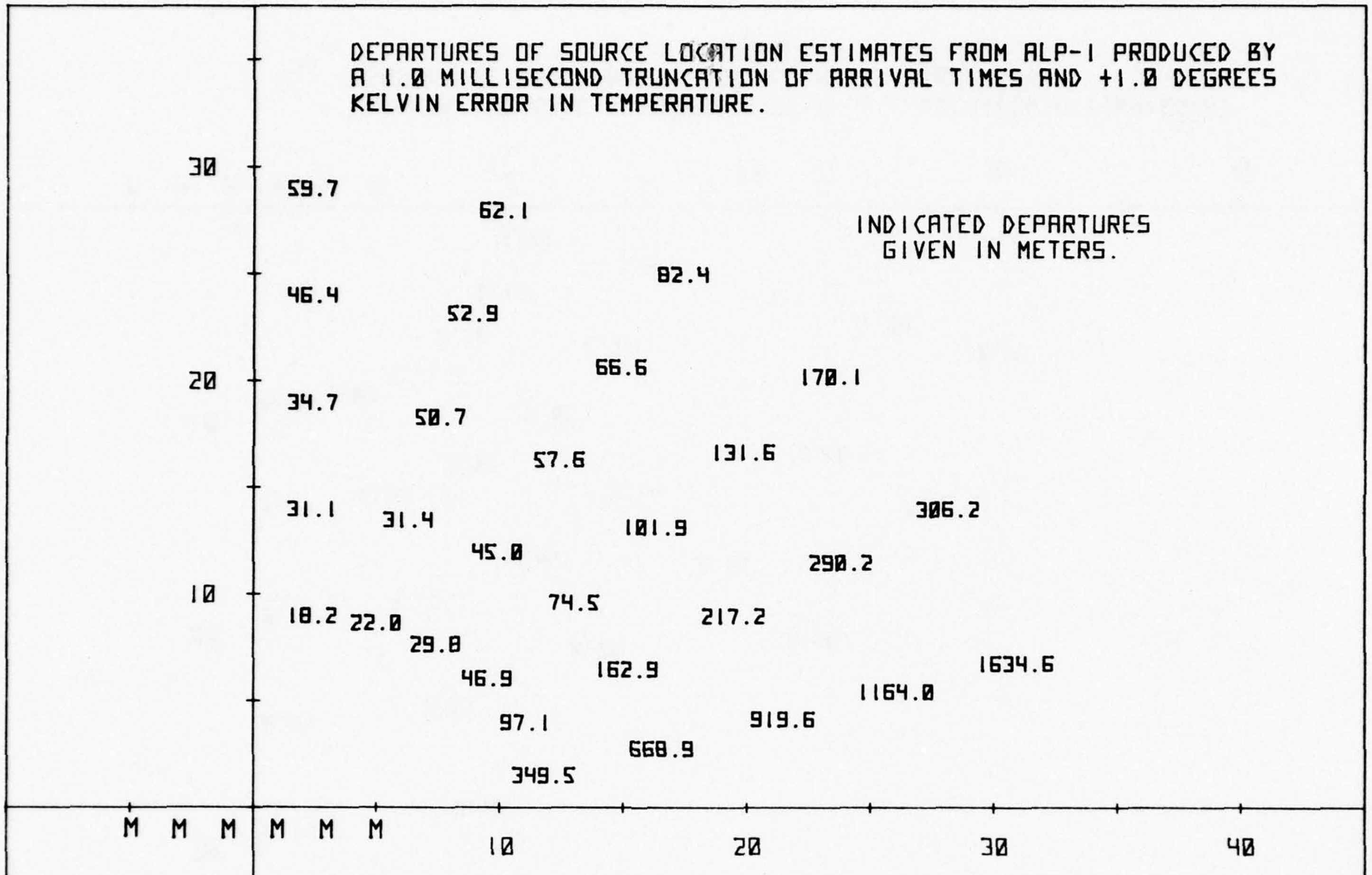
FIGURE 6

DEPARTURES OF SOURCE LOCATION ESTIMATES FROM ALP-1 EXPRESSED AS PERCENT OF RANGE. ARRIVAL TIMES ARE TRUNCATED AT THE NEAREST 10 MILLISECONDS. UNIFORM SCALE REPRESENTS 5.0 KILOMETERS.



NUMBERS INDICATE DEPARTURES OF SOURCE LOCATION ESTIMATES AT RESPECTIVE POSITIONS AS INDICATED IN FIGURE 1.

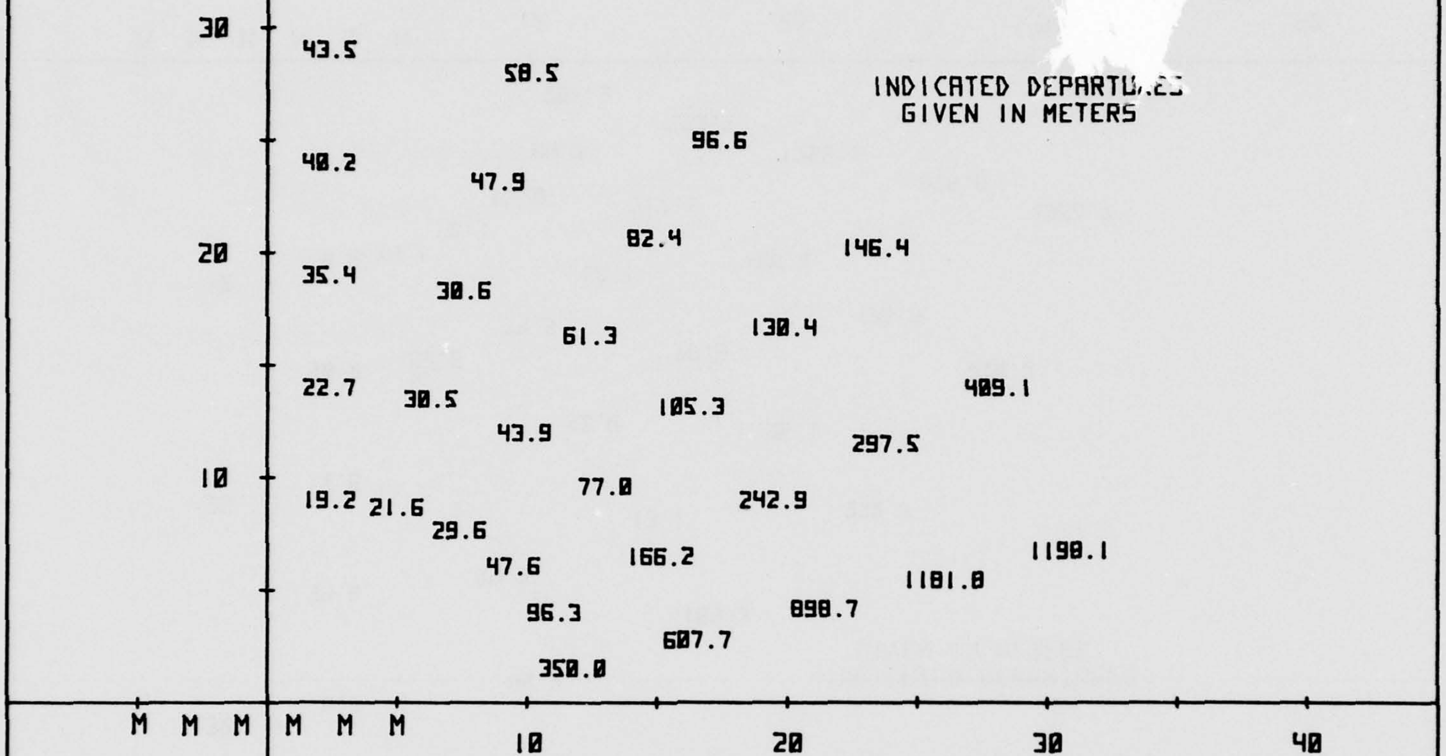
FIGURE 7



NUMBERS INDICATE DEPARTURES OF SOURCE LOCATION ESTIMATES AT RESPECTIVE POSITIONS AS INDICATED IN FIGURE 1.

FIGURE 8

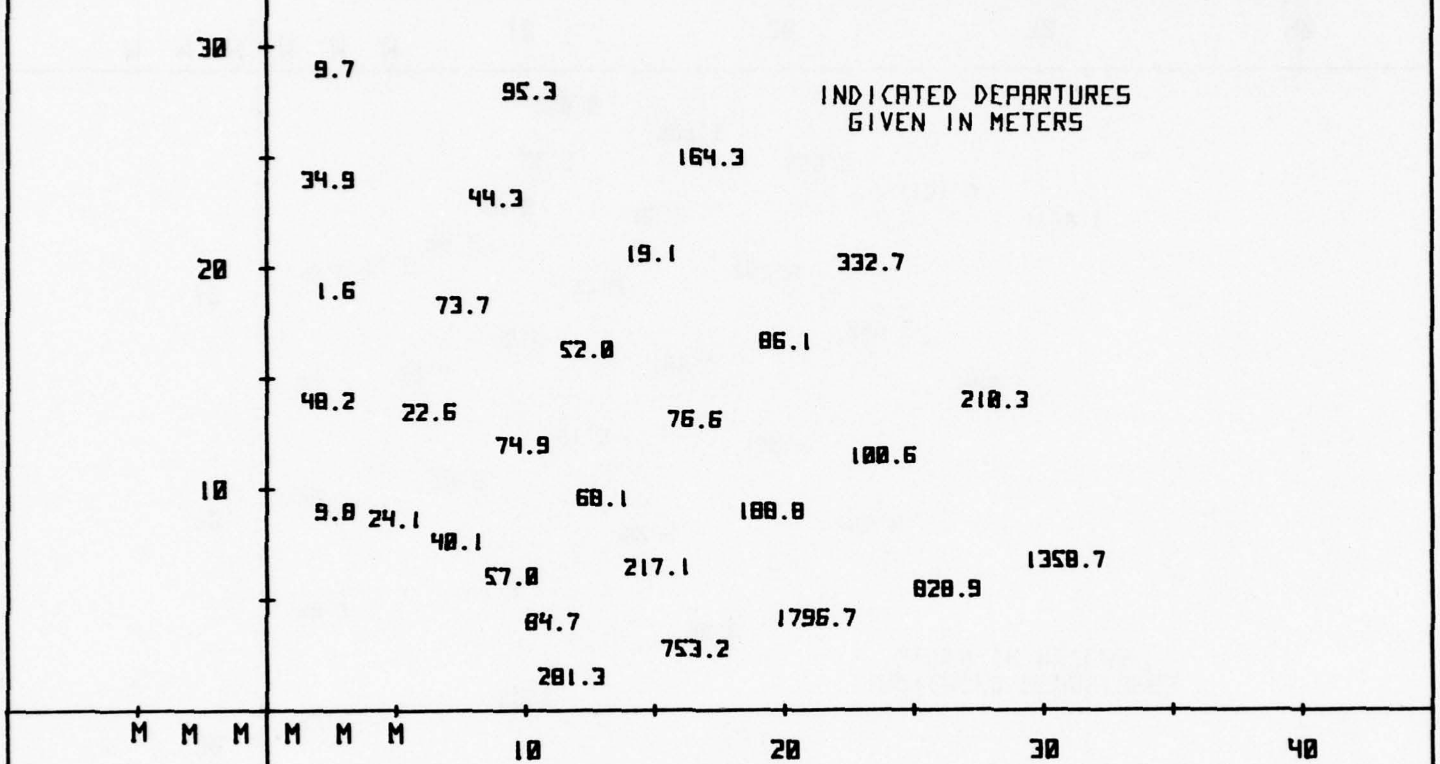
DEPARTURES OF SOURCE LOCATION ESTIMATES FROM [illegible] DUCED BY A 1.0 MILLISECOND TRUNCATION OF ARRIVAL TIME[illegible] 0 DEGREES KELVIN ERROR IN TEMPERATURE.



NUMBERS INDICATE DEPARTURES OF SOURCE LOCATION ESTIMATES AT RESPECTIVE POSITIONS AS INDICATED IN FIGURE 1.

FIGURE 9

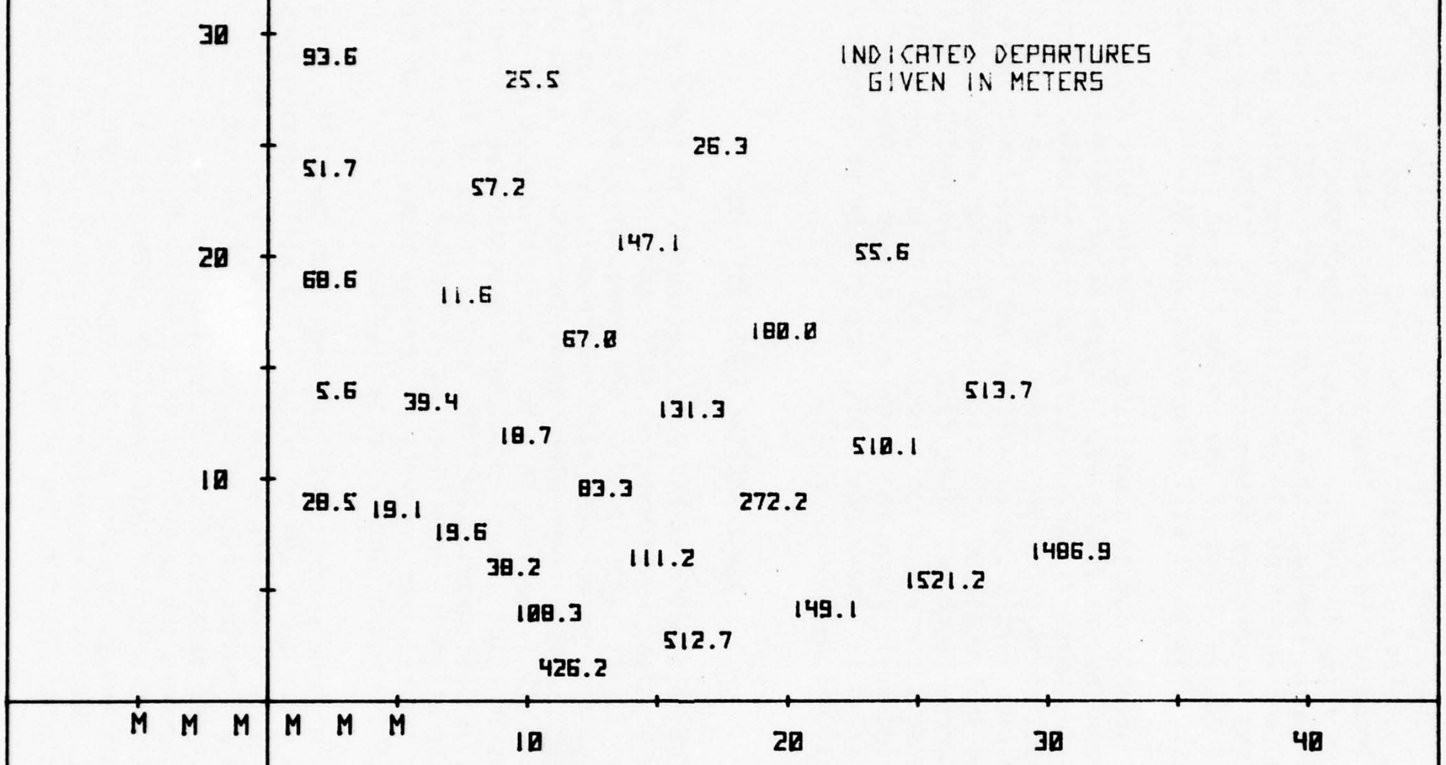
DEPARTURES OF SOURCE LOCATION ESTIMATES DERIVED FROM ALP-1 AND INCLUDING A 10 MILLISECOND TRUNCATION OF ARRIVAL TIMES. ALSO PRESENT IS A +1.0 DEGREES KELVIN ERROR IN TEMPERATURE.



NUMBERS INDICATE DEPARTURES OF SOURCE LOCATION ESTIMATES AT RESPECTIVE POSITIONS AS INDICATED IN FIGURE 1.

FIGURE 10

DEPARTURES OF SOURCE LOCATION ESTIMATES DERIVED FROM ALP-1 AND INCLUDING A 10 MILLISECOND TRUNCATION OF ARRIVAL TIMES. ALSO PRESENT IS A -1.0 DEGREES KELVIN ERROR IN TEMPERATURE.



NUMBERS INDICATE DEPARTURES OF SOURCE LOCATION ESTIMATES AT RESPECTIVE POSITIONS AS INDICATED IN FIGURE 1.

FIGURE 11

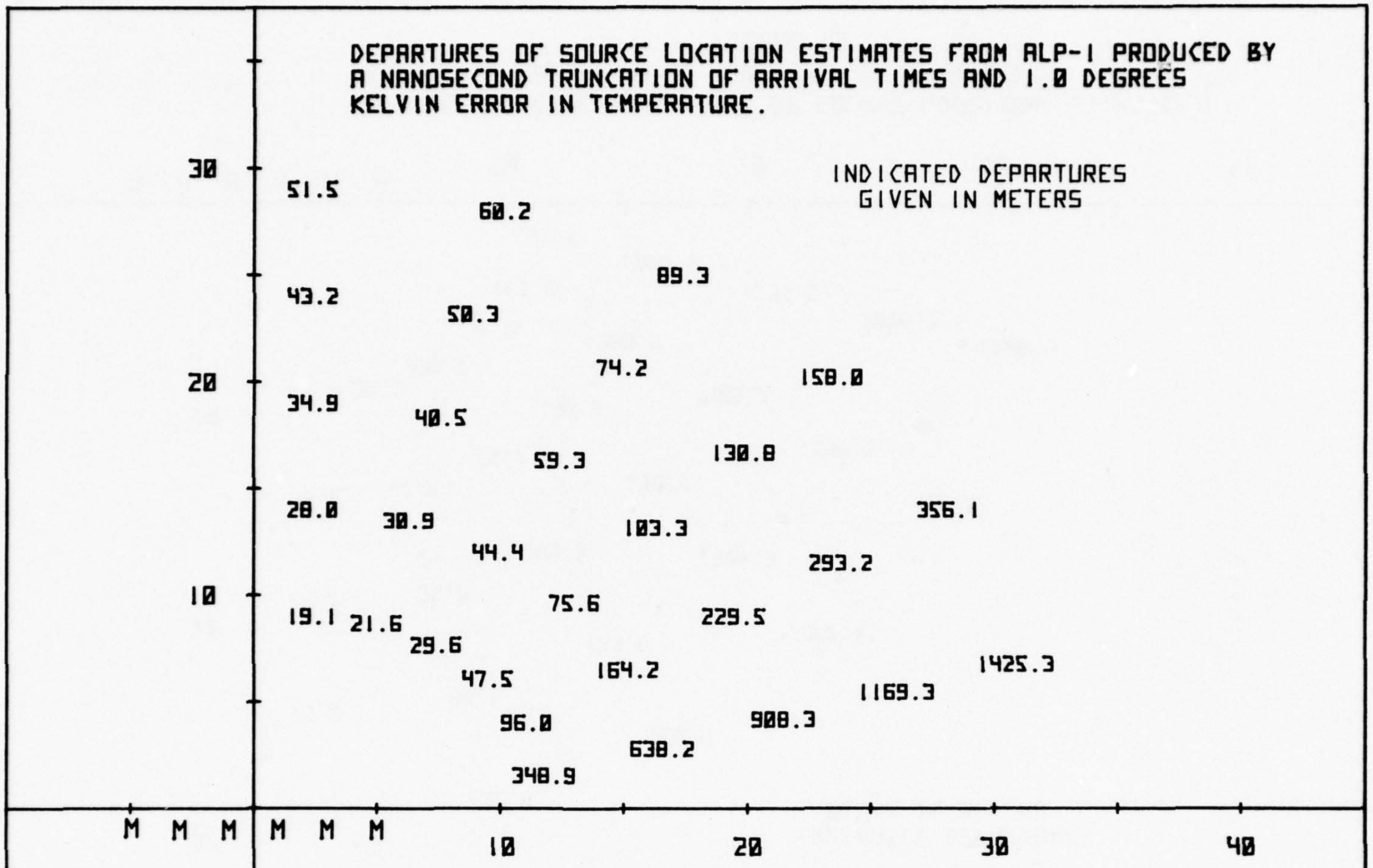
True unit effects which utilize full possible timing accuracy are given in Fig. 12. These effects represent a unit variation in temperature in either a positive or negative sense, and are consistent. Note that respective locations in Fig. 12 are very nearly averages from Figs. 8 and 9 or from Figs. 10 and 11. A point which should be noted is that as flanking angles approach zero degrees, unit effects diminish considerably. Another method of viewing this condition which will prove pertinent is that temperature information occurs further and further to the right of the decimal point of the timing data as flanking angles decrease to 0 degrees. This point will also arise when ALP-2 is introduced.

In Fig. 13, effects due to a positively oriented unit wind parallel to the array baseline are displayed. Figure 14 offers identical information for a unit wind which is perpendicular to this baseline. Notice the drastic reduction in error magnitudes in Fig. 14. In fact, if Fig. 14 is compared with errors due to millisecond truncation (Fig. 4), it might be suspected that position estimates must be independent of winds perpendicular to array baseline. This fact is further verified by Fig. 15 which represents the effect of a vector sum of unit coordinate winds. It can be rigorously shown that such must always be the case in so far as the linear array is concerned. This fact will be of considerable importance in the construction of ALP-2.

ALP-2 AND THE CORRECTIVE MODE

The algorithm designated as ALP-2 is constructed to function optimally in the same physical environment as ALP-1 and is fabricated by way of [2], section 5. It is tailored to the linear array and requires a configuration of five or more acoustic microphones, as contrasted to the requirement of three or more microphones for ALP-1. On the positive side, the algorithm ALP-2 operates in a full corrective mode and will recover source point location even when subject to considerable errors in wind and temperature estimates, providing arrival times at the microphones under consideration are determined to sufficient accuracy. In fact, one may balance the required accuracy of arrival times against the necessary integrity of the meteorological data involved.

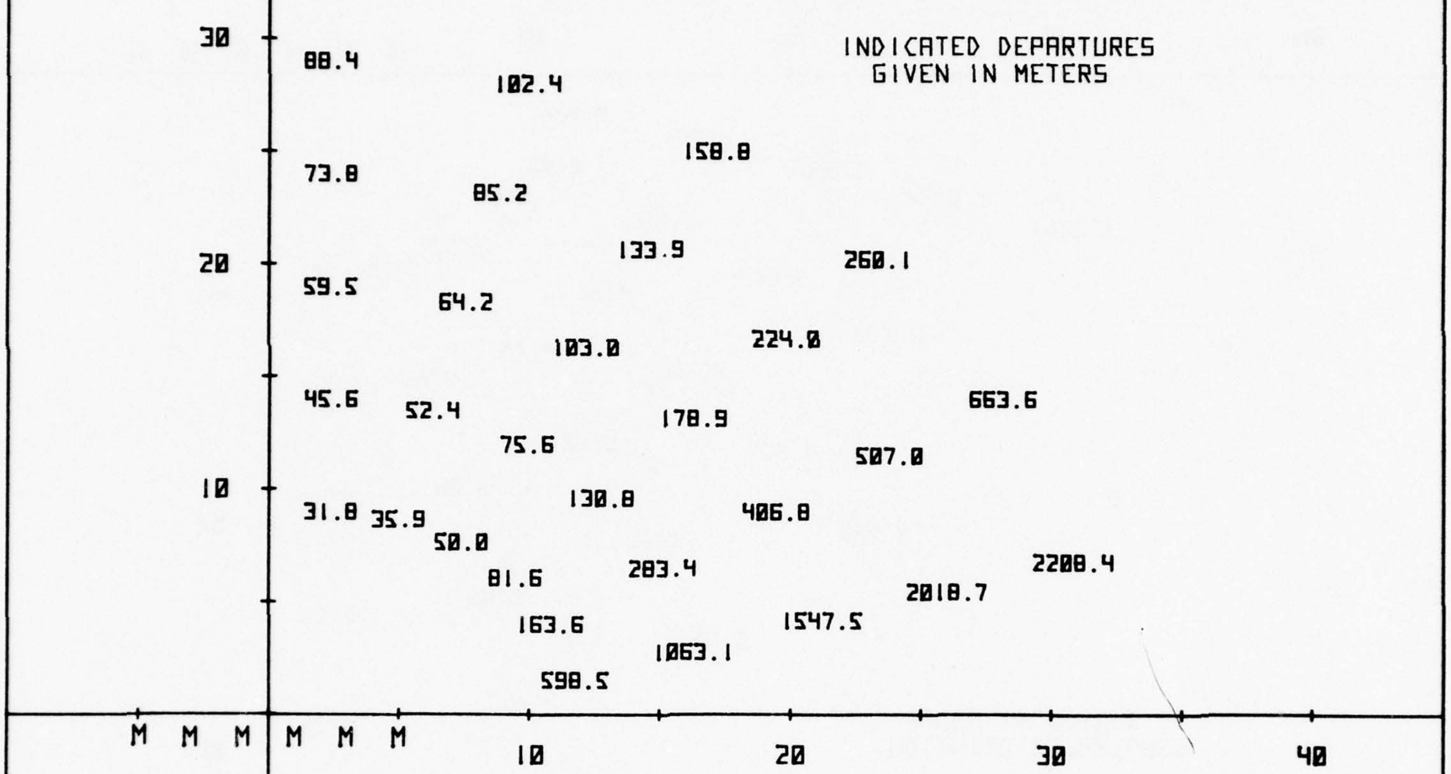
Examination with near exact data has indicated that with a preliminary estimate in error up to 20% of range, ALP-2 will function consistently to a range of 10 kilometers and a flanking angle of 75 degrees, or 12 kilometers with a flanking angle of 60 degrees. A more complete picture is presented if one examines those source locations as indicated in Fig. 16. Figure 17 presents the departures in estimates derived from ALP-1 and caused by a wind error of unit magnitude (meters/second) in the direction of positive x and y, together with a temperature error of +1.0° kelvin. This is with regards to respective source points from Fig. 16 in excess of 2 kilometers. The behavior of ALP-1 at the 2-kilometer range is



NUMBERS INDICATE DEPARTURES OF SOURCE LOCATION ESTIMATES AT RESPECTIVE POSITIONS AS INDICATED IN FIGURE 1.

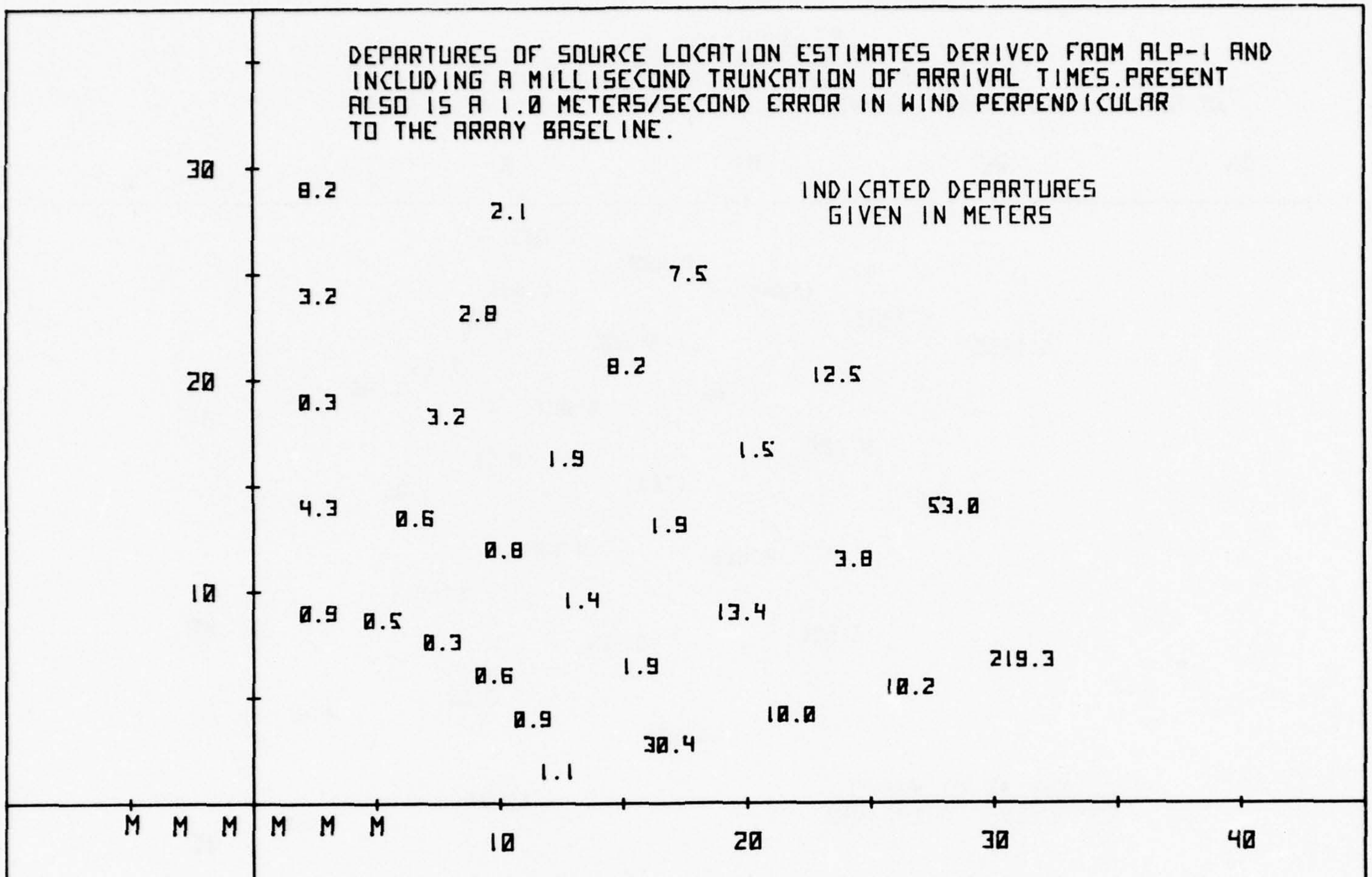
FIGURE 12

DEPARTURES OF SOURCE LOCATION ESTIMATES FROM ALP-1 PRODUCED BY A 1.0 MILLISECOND TRUNCATION OF ARRIVAL TIMES AND A WIND ERROR OF 1.0 METERS/SECOND PARALLEL TO ARRAY BASELINE.



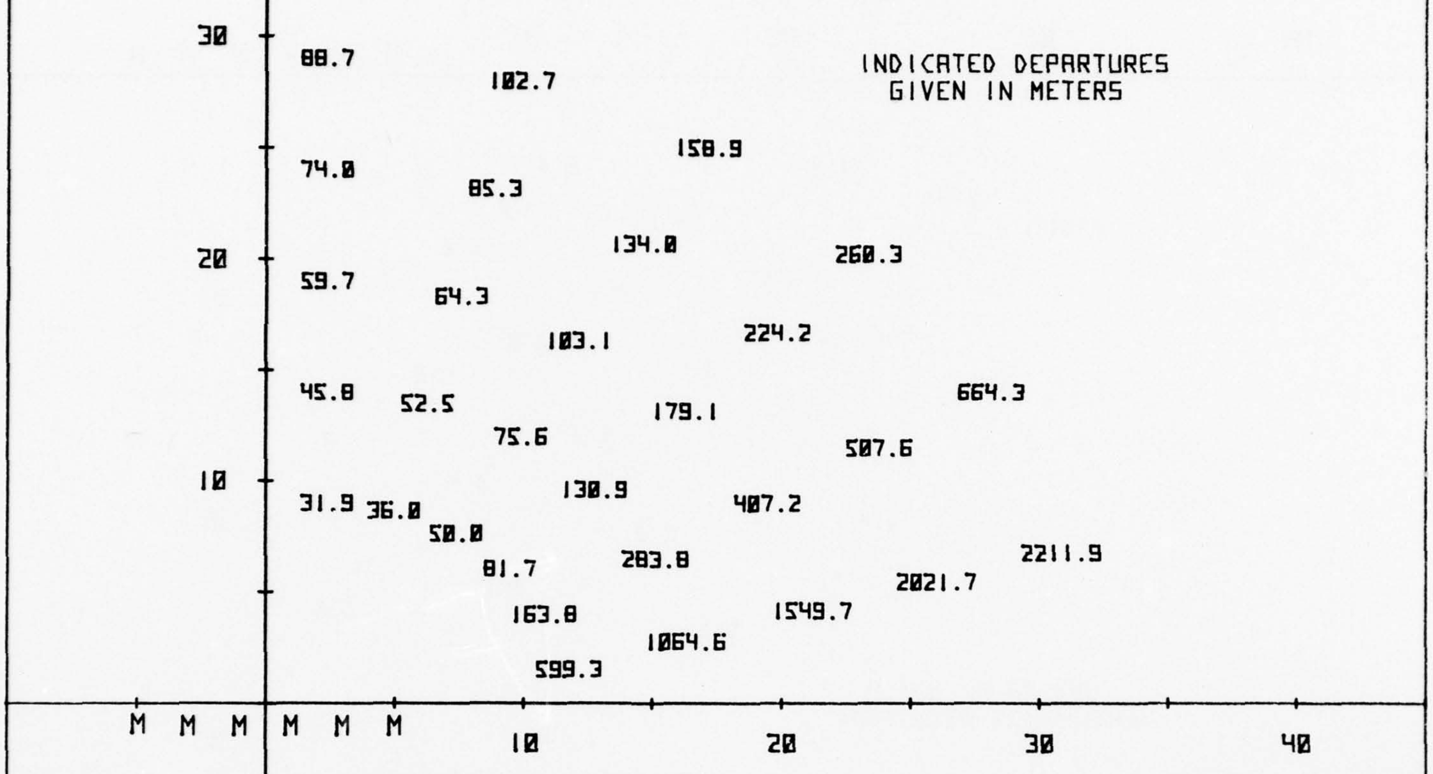
NUMBERS INDICATE DEPARTURES OF SOURCE LOCATION ESTIMATES AT RESPECTIVE POSITIONS AS INDICATED IN FIGURE 1.

FIGURE 13



NUMBERS INDICATE DEPARTURES OF SOURCE LOCATION ESTIMATES AT RESPECTIVE POSITIONS AS INDICATED IN FIGURE 1.
FIGURE 14

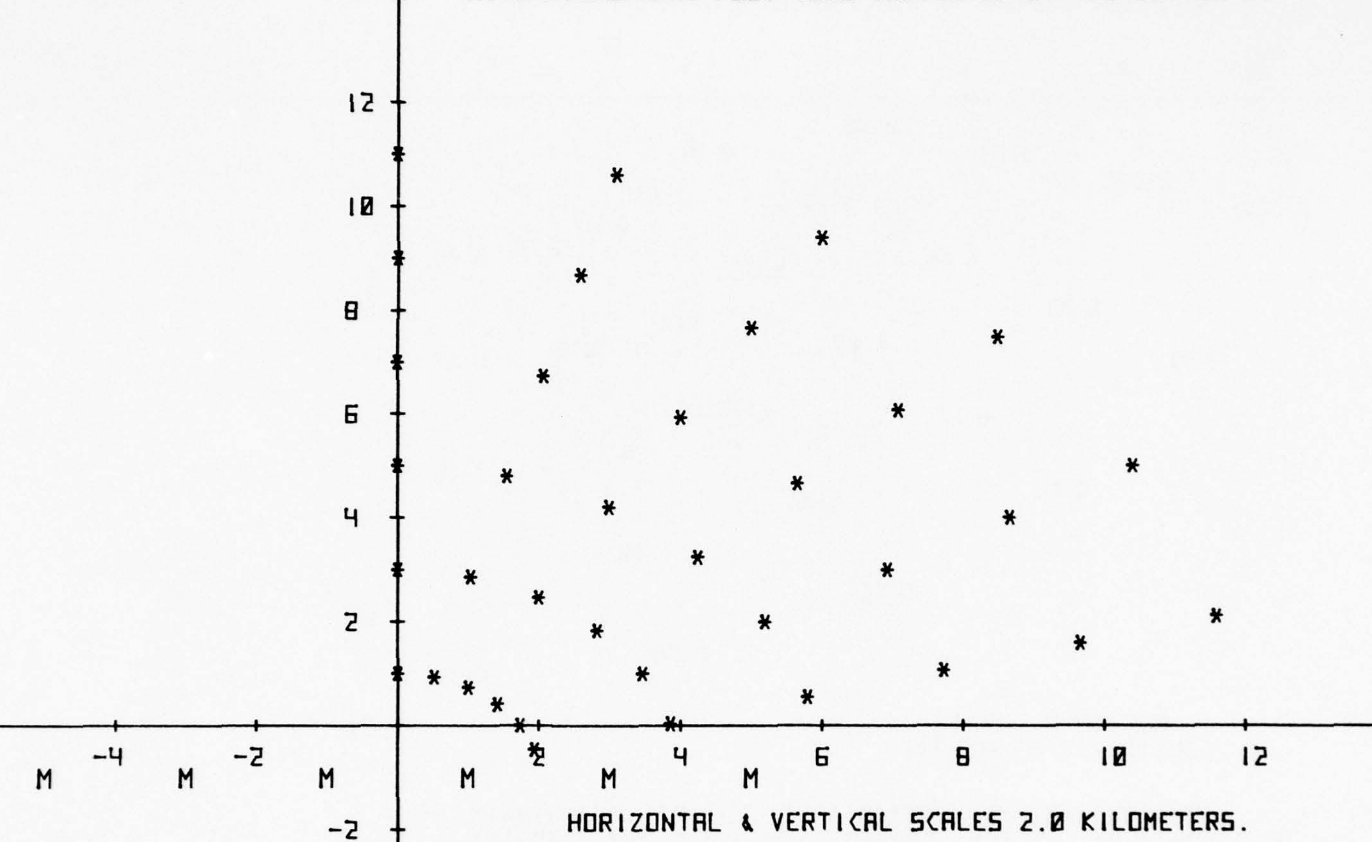
DEPARTURES OF SOURCE LOCATION ESTIMATES FROM ALP-1 PRODUCED BY A 1.0 MILLISECOND TRUNCATION OF ARRIVAL TIMES AND A WIND ERROR OF 1.4 METERS/SECOND 45 DEGREES OFF ARRAY BASELINE.



NUMBERS INDICATE DEPARTURES OF SOURCE LOCATION ESTIMATES AT RESPECTIVE POSITIONS AS INDICATED IN FIGURE 1.

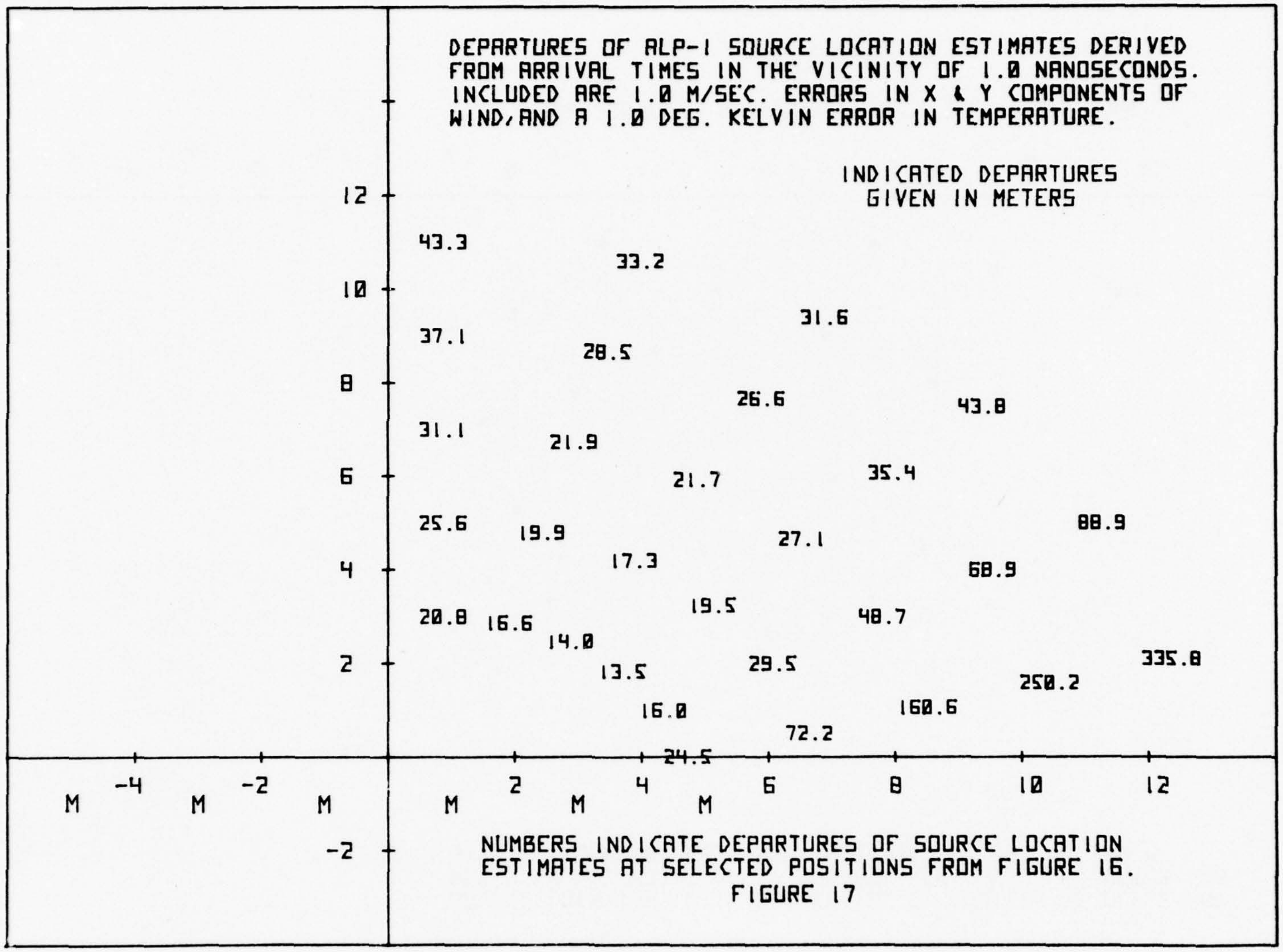
FIGURE 15

SOURCE LOCATIONS UTILIZED IN THE EVALUATION OF ALP-2 AND ALP-3.SOURCE POINT POSITIONS ARE DESIGNATED BY ASTERISKS WITH MICROPHONE POSITIONS INDICATED BY THE LETTER M.



HORIZONTAL & VERTICAL SCALES 2.0 KILOMETERS.

FIGURE 16



NUMBERS INDICATE DEPARTURES OF SOURCE LOCATION ESTIMATES AT SELECTED POSITIONS FROM FIGURE 16.
FIGURE 17

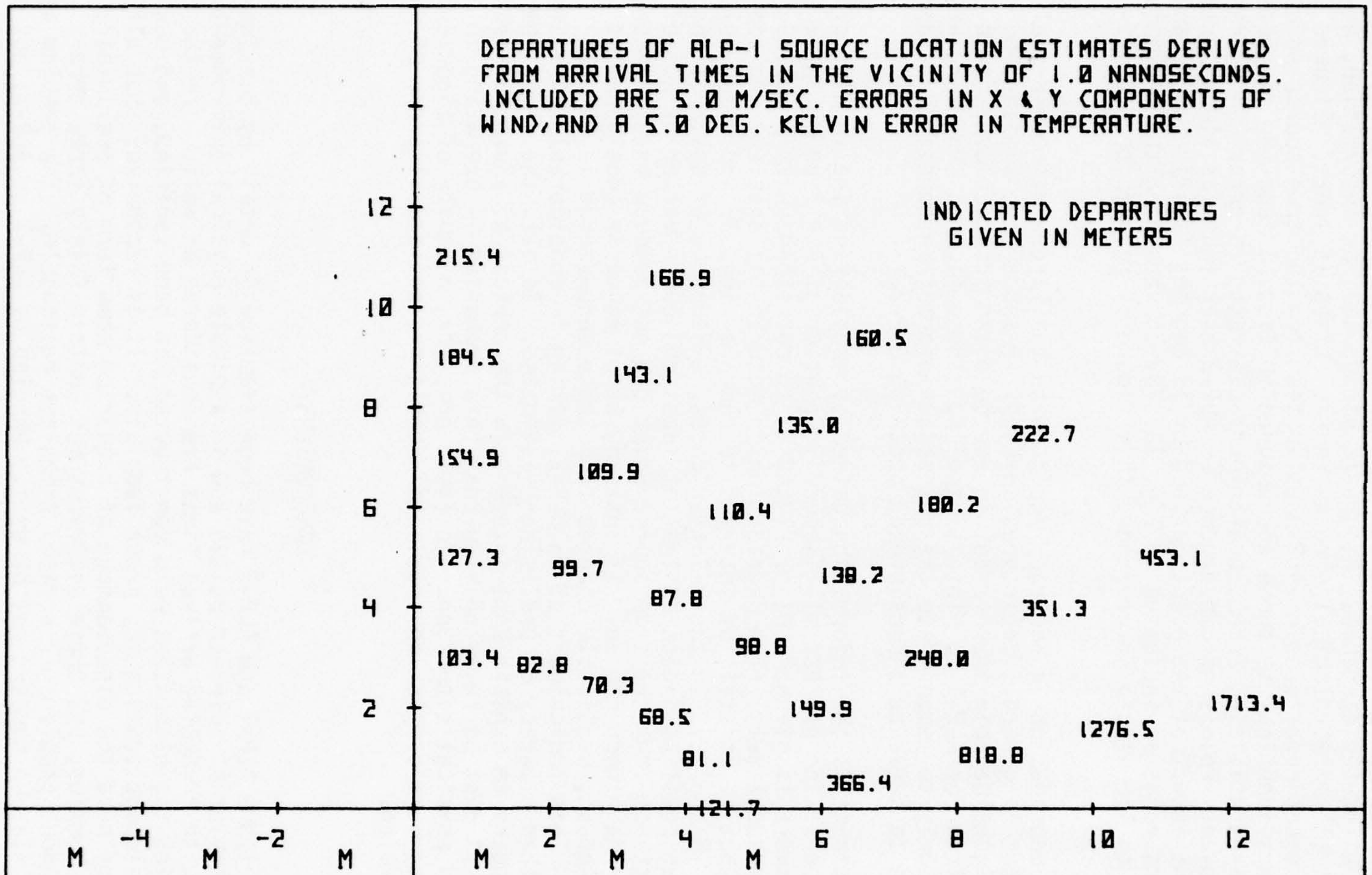
omitted for editorial reasons, and departures are in all cases smallest at the 2-kilometer distance. Figure 18 yields similar information, except that all meteorological errors are five times as great. Figures 19 and 20 present departures of ALP-2 estimates from the true source points with errors identical to those encountered in Figs. 17 and 18, respectively. In all cases utilizing ALP-2, preliminary estimates in error 20% of range are employed. Points of convergence of ALP-2 have thus far always proved consistent except at the point defined by 75 degrees flanking angle and 12 kilometers range as indicated in Fig. 18. By constraining the preliminary estimate to lie within 5% of range, this figure is reduced to 3 centimeters.

A slight degradation in accuracy occurs with the larger meteorological errors; but in general, departures in Figs. 19 and 20 are similar and represent a considerable improvement in source point location over those values given for ALP-1 in Figs. 17 and 18. These figures, however, are intended only to demonstrate the potential information contained in arrival times and to serve as a consistency check on ALP-2.

More pertinent is the information gained by considering the results of truncation at the nearest millisecond. Behavior of ALP-2 under these circumstances is given in Figs. 21 and 22 to correspond with Figs. 19 and 20, respectively. The degradation in accuracy is apparent and conclusive, but it is still of interest to compare Figs. 17 and 21 as well as Figs. 18 and 22. In these latter cases, a sequence of dollar signs at a given position indicates that at least one guess vector at 20% of range distance from the true source point did not produce results identical to the others chosen. If instead, 5% of range is considered as an error-bound, negligible changes from those encountered in Fig. 22 are met. This indicates that in ALP-2, timing is considerably more important than accuracy of preliminary estimates. In all, the algorithm ALP-2 appears to exhibit some interest in the context of advancing technology. It must be recalled also that this mechanism is operating in an idealized physical situation. In field practice, a family of algorithms reflecting more complex environmental conditions could well prove of greater value.

CONCLUSIONS

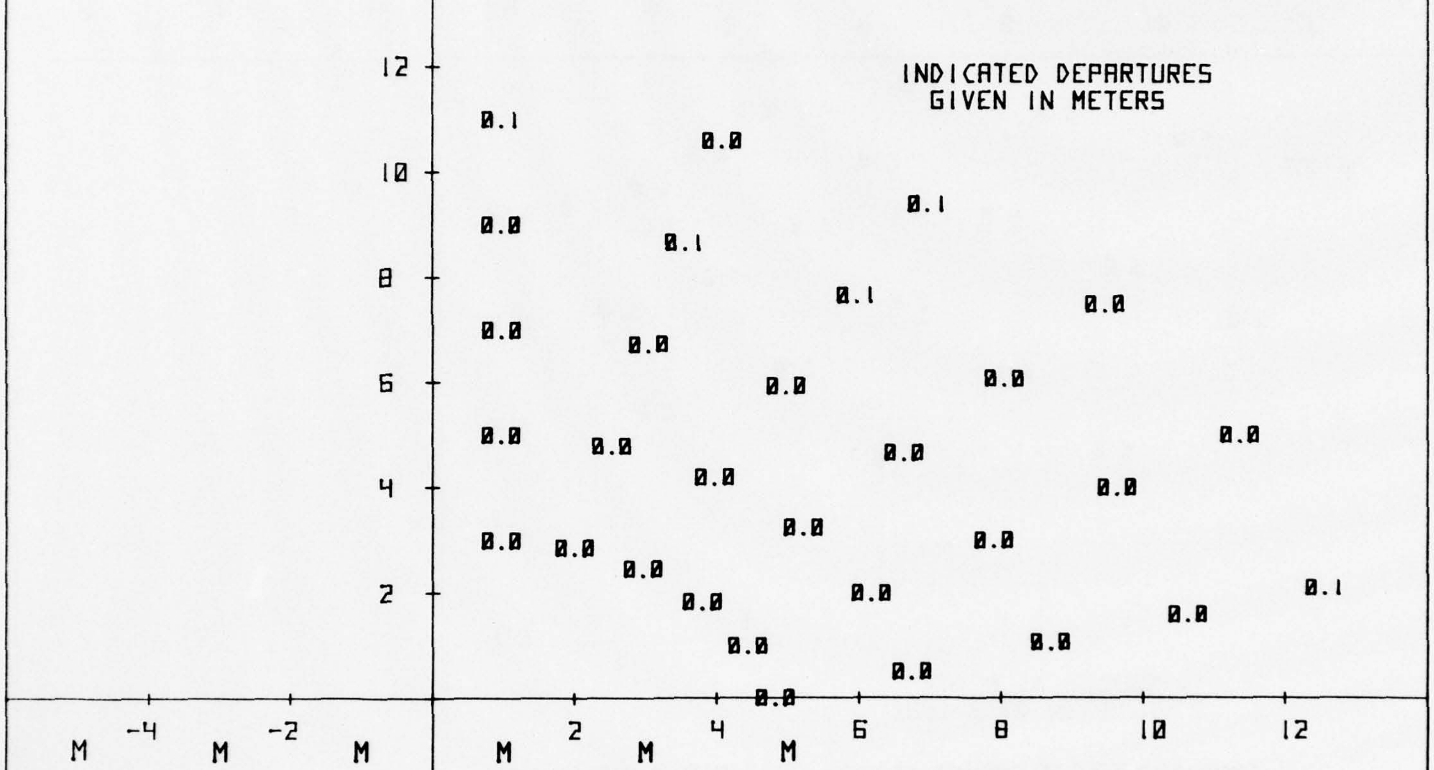
The algorithms ALP-1 and ALP-2 have been examined in detail by considering their behavior at selected points and in a simple physical environment. Systems with truncated arrival times are considered as well. The theory under which the algorithms were constructed has been verified, and possible field application may prove feasible. It is recognized that all ALP algorithms have the disadvantage of requiring some form of preliminary source estimates, but these estimates may contain fairly large errors without undue problems if arrival times are reasonable. The problem of reducing station numbers may be easily handled by ALP-1 or ALP-2; but only



NUMBERS INDICATE DEPARTURES OF SOURCE LOCATION ESTIMATES AT SELECTED POSITIONS FROM FIGURE 16.

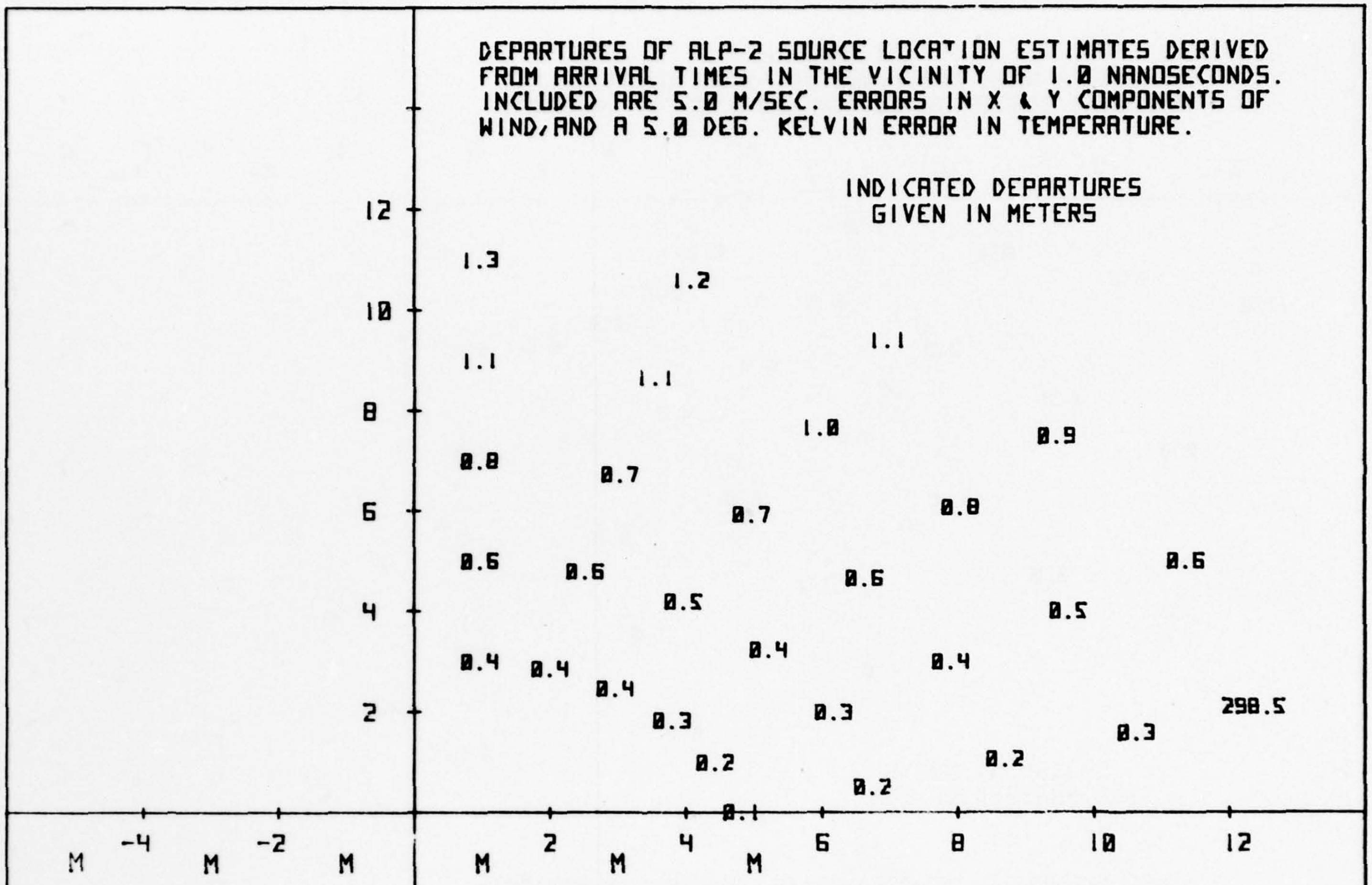
FIGURE 18

DEPARTURES OF ALP-2 SOURCE LOCATION ESTIMATES DERIVED FROM ARRIVAL TIMES IN THE VICINITY OF 1.0 NANOSECONDS. INCLUDED ARE 1.0 M/SEC. ERRORS IN X & Y COMPONENTS OF WIND, AND A 1.0 DEG. KELVIN ERROR IN TEMPERATURE.



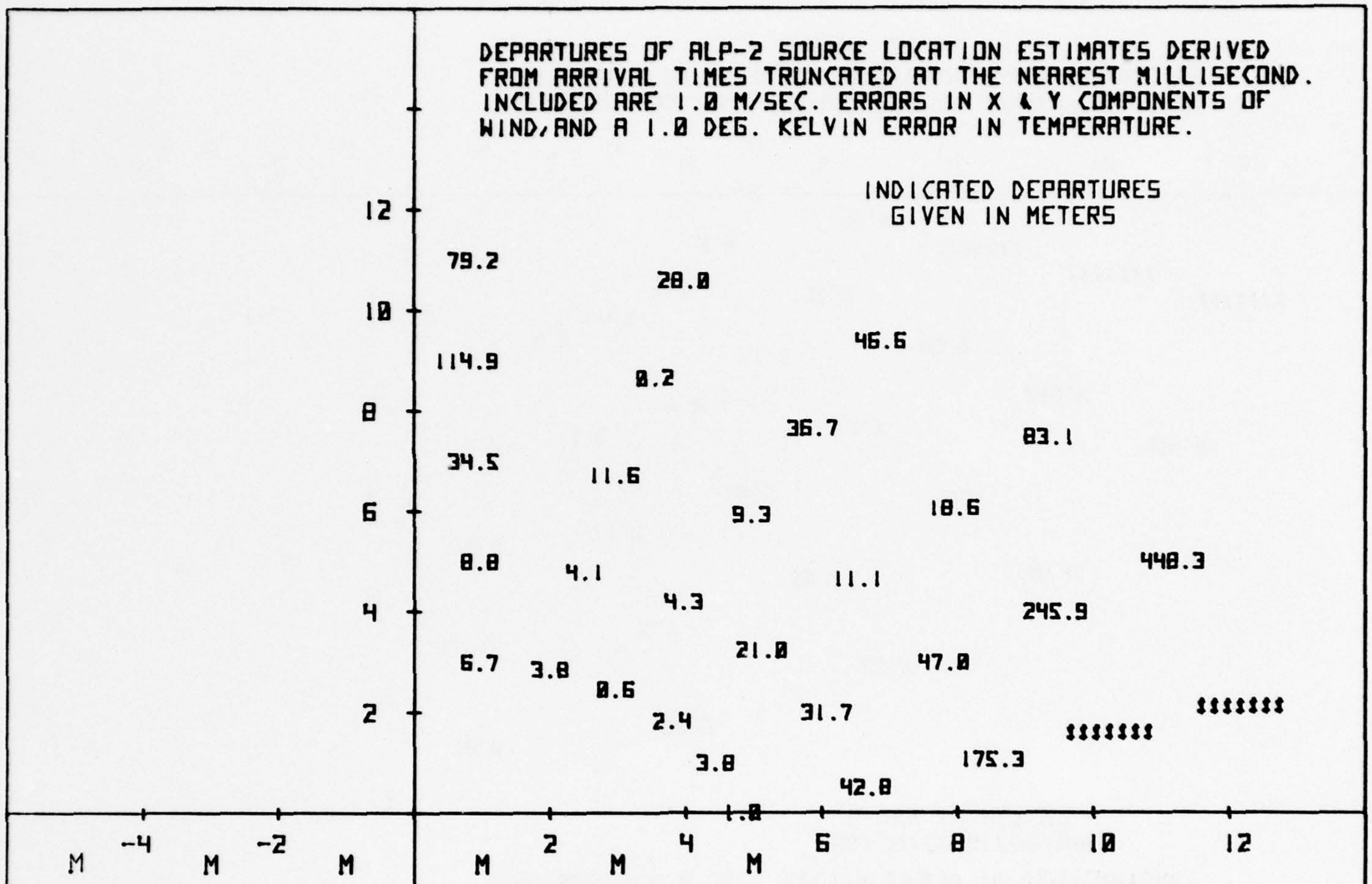
NUMBERS INDICATE DEPARTURES OF SOURCE LOCATION ESTIMATES AT SELECTED POSITIONS FROM FIGURE 16.

FIGURE 19



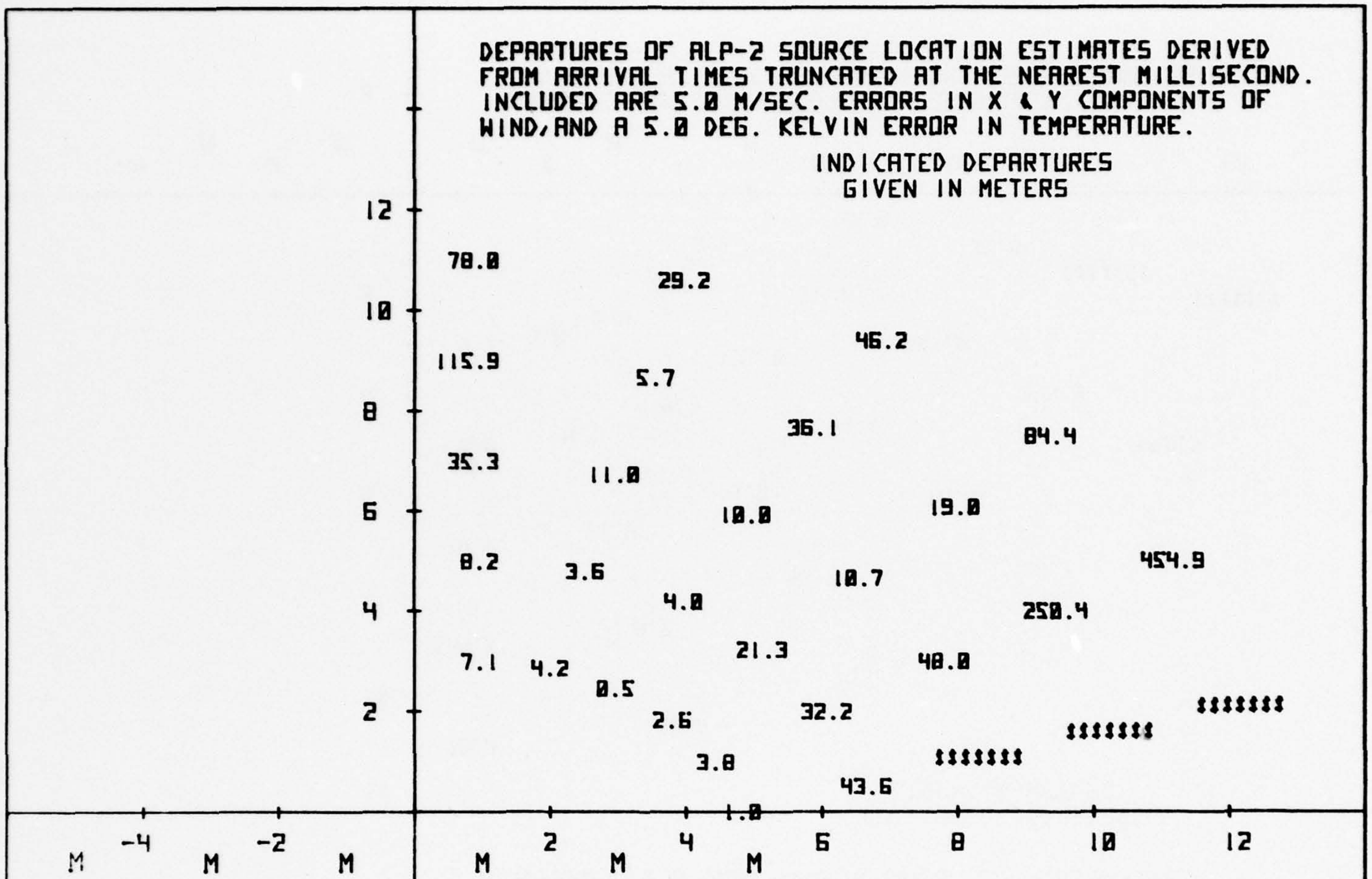
NUMBERS INDICATE DEPARTURES OF SOURCE LOCATION ESTIMATES AT SELECTED POSITIONS FROM FIGURE 16.

FIGURE 20



NUMBERS INDICATE DEPARTURES OF SOURCE LOCATION ESTIMATES AT SELECTED POSITIONS FROM FIGURE 16.

FIGURE 21



NUMBERS INDICATE DEPARTURES OF SOURCE LOCATION ESTIMATES AT SELECTED POSITIONS FROM FIGURE 16.

FIGURE 22

one microphone may be lost in ALP-2, while ALP-1 permits loss of three. In addition, ALP-1 is independent of array construction, while ALP-2 requires a linear array of acoustic microphones for full correction.

A modification of ALP-2 is already written which will permit use of nonlinear arrays and will require five or more operative microphones for corrective mode. Unfortunately, this modification will not permit use of a linear array. General nonlinear arrays are being constructed, including random dispersions. From study of such arrays, a degree of "focusing" or optimizing may be possible.

REFERENCES

1. FM 6-122, Artillery Sound Ranging and Flash Ranging, 1964, Dept of Army, Washington, DC.

2. Miller, Walter B. and B. F. Engebos, 1976, A Mathematical Structure for Refinement of Sound Ranging Estimates, ECOM-5805, Atmospheric Sciences Laboratory (ASL), US Army Electronics Command, White Sands Missile Range (WSMR), NM.

3. Rachele, Henry, 1966, A Specialized Acoustic Array Solution, ASL, WSMR, NM, unpublished manuscript.

4. Lee, Robert P., 1972, Artillery Sound Ranging Computer Simulations, ECOM-5441, ASL, US Army Electronics Command, WSMR, NM.

BIBLIOGRAPHY

1. Denver Research Institute, 1956, "Study of Meteorological and Terrain Factors which Affect Sound Ranging - Final Report," University of Denver, Denver, CO (AD 139326).

2. Bellucci, Raymond, 1963, "Studies of Meteorological Techniques for Sound Ranging, Part 1," USAERDL Technical Report 2367, US Army Research and Development Laboratory, Fort Monmouth, NJ.

3. Bellucci, Raymond, 1966, "Studies of Meteorological Techniques for Sound Ranging, Report 11, Error Analysis," Technical Report ECOM-2703, Atmospheric Sciences Laboratory, US Army Electronics Command, Fort Monmouth, NJ.

4. Barichivich, Anthony, 1966, "Proposed New Meteorological Techniques for Sound Ranging, Report 111," Technical Report ECOM-2702, Atmospheric Sciences Laboratory, US Army Electronics Command, Fort Monmouth, NJ.

5. Lee, R. P., 1967, "A Probabilistic Model for Acoustic Sound Ranging," ECOM-5159, Atmospheric Sciences Laboratory, US Army Electronics Command, White Sands Missile Range, NM (AD 664117).

6. Lee, R. P., 1969, "A Dimensional Analysis of the Errors of Atmospheric Sound Ranging," ECOM-5236, Atmospheric Sciences Laboratory, US Army Electronics Command, White Sands Missile Range, NM (AD 686287).

7. Kennedy, W. B., et al., 1956, "Study of Meteorological and Terrain Factors which Affect Sound Ranging - Final Report," Denver Research Institute, University of Denver, Denver, CO.

8. Diamond, M. and R. P. Lee, 1965, "Long-Range Atmospheric Sound Propagation," J. Geophys. Res., Vol. 70, No. 22.

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